DOCUMENT RESUME

ED 137 885 CS 501 698

AUTHOR	Monge, Peter R.; And Others
TITLE	The Location of Information Processing Organizations.
PUB DATE	Jun 77
NOTE	43p.; Paper presented at the Annual Meeting of the International Communication Association (27th, Berlin, West Germany, May 29-June 4, 1977)
EDRS PRICE	MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS	Agencies; *Cost Effectiveness; Economic Research; Information Dissemination; *Information Processing; *Information Science; Models; Statistical Analysis
IDENTIFIERS	*Location Theory

ABSTRACT

Location theory was extended into the domain of information-processing firms by attempting to optimally place a federal research and development agency according to its information-processing functions. The techniques used consisted of identifying possible locations within the continental United States, examining the costs of performing the research functions at each location, and using linear optimization to select the location which would minimize costs. Costs of electrical power, transportation of materials, and travel were considered, as were environmental requirements (i.e., weather and altitude). The first analysis examined currently existing information sources; the second postulated an ideal information supply and attempted to maximize information input fr m that ideal source. The results indicated that the federal research and development agency examined was optimally located within organizational constraints. The utility of the procedures for locating information-processing organizations was also demonstrated. (Author/AA)

THE LOCATION OF INFORMATION PROCESSING ORGANIZATIONS[1]

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Paper Presented to the
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Annual Convention of the International
Communication Association, Berlin, West Germany
June 1977.

[1]The authors wish to express their appreciation to Mr. Peter Chastain for his assistance in developing and programming the computer algorithm utilized in this research.

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ABSTRACT

Traditional location theory, a relatively recent branch of economics, has focused primarily on locating organizations which manufacture material commodities. The present paper extends this work into the domain of information processing firms by attempting to optimally locate a research and development agency according to its information processing functions.

The technique used to conduct the study consisted of identifying possible alternative research location areas within the continental United States, examining the costs of performing the research functions at each location, and using linear optimization to select that location which minimizes such costs. Locations were determined by imposing a fifty-by-fifty-mile grid on a map of the U.S. Electrical power costs for each location were calculated as were the costs associated with transporting a representative sample of material inputs from their present sources to each of one thousand three hundred twenty-five potential locations. A function was formulated to account for the acquisition, use, and transfer of information. This information function was operationalized as the cost of travel to and from universities, industries, government installations, and conferences. Environmental requirements (i.e., weather and altitude), were also imposed to identify those sites which meet performance criteria.

Two separate analyses were undertaken. The first analysis examined currently existing information sources; the second postulated an ideal information supply surface and attempted to maximize information input from that ideal source. The results indicated that the federal research and development agency was optimally located within organizational constraints. The utility of the procedures for locating information processing organizations was also demonstrated.

I. INTRODUCTION AND STATEMENT OF PROBLEM

One of the major problems facing both well-established and new organizations is the selection of optimal locations for facilities. Its significance lies in the fact that site location will have major effects on both productivity and efficiency. The problem is basically that of defining an organizations' relevant environment, those aspects of the physical and economic worlds with which an organization seeks to maximize contact. There are, of course, numerous dimensions to the problem, but the search for solutions always rests on the belief that maximizing this relevant environment will maximize productivity and efficiency.

Prior to the early 1960's, the location of most organizations was pretty much an historical accident. During the early 1960's several methods were developed for locating <u>manufacturing</u> organizations according to optimal criteria. Typical constraints in these early location analyses were such factors as proximity to raw inputs, proximity to the marketplace, transportation costs, availability of labor and so forth. Unfortunately, these early models of manufacturing firms are of little use when it comes to organizations which primarily produce <u>information</u> rather than physical commodities and goods, i.e., to research and development organizations. The relevant environment for manufacturing organizations is quite different from that of organizations

predominantly concerned with the production of information.

This problem defines the focus of this paper: We shall attempt to extend traditional locational analyses to the problem of locating an information rather than commodities processing organization. A federal agency, whose primary mission is research and development, will be used as an exemplar of an information processing organization. To accomplish the location task two separate analyses will be undertaken. Analysis I will attempt to determine where the research and development functions performed by the Agency should be located based upon current information and material sources so as to maximize research efficiency and minimize cost. Analysis II will use the same locational procedure with the exception that optimal potential information sources will be substituted for current ones. These sources consist of the highest rated universities and industries throughout the continental United States that can meet the research and development needs of the Agency. Both analyses are based upon the branch of economics known as location theory and will locate the research complex via mathematical programming techniques applied simultaneously to its material and information inputs.

II. THE ROLE OF INFORMATION IN LOCATING THEORY

Traditional location theory has concentrated on conditions to be satisfied in the placing of firms, industries, and organizations that produce predominantly physical commodities rather than information. This theory has a long history in the economic literature and began as part of general equilibrium theory in the works of Von Thunen (1846), Weber (1929), Launhardt (1882), and Losch (1954), and has resulted in the more contemporary theories of Hoover (1948), Isard (1956), Tornqvist (1968, 1971), and others.

Weber's classical studies concentrated on different aspects of the problems of locating single factories and problems connected with the creation of agglomerations. There are a number of assumptions common to all so-called Weber models. They deal with single products. Any products of differing quality, though of similar type, are treated as different products. All input sources are assumed to be known. Similarly, all output destinations are assumed to be known. It is assumed that there exists a number of fixed places where labor, at fixed known wages is available in unlimited quantities and, finally, transportation costs are a function of distance and weight.

In looking at the problem of locating a single factory, Weber admitted the possibility that several alternative locations may supply any factory with a given input. He did not provide any satisfactory discussion of the implication of such a situation for the form of a profit function which includes transport cost and the location of a factory. Usually, in Weberian models, it is thus assumed that trade partners of any factory and their locations are given.

Von Thunen and Weber both attempted to create abstract location theories which were consistent with general equilibrium solutions. Von Thunen concentrated on developing laws which determine production best carried out at any given place, restricting his analysis to agricultural production and land rent as influenced by distance from the marketplace. The majority of such location theory, consonant with general equilibrium analysis while nicely illuminating a number of theoretical problems has proven comparatively useless for the analysis of real world location situations.

Recent research in industrial location theory, while only peripherally concerned with formulation of general theory, has still concentrated mainly on industrial and organizational units which produce physical commodities rather than information. With few exceptions, the majority of research has followed

a partial equilibrium approach which holds fixed the locations and costs of all resources.

The substitution principle is the most common procedure used to relax such assumptions. If, for example, one is given differences in transportation costs as a function of distance, one can then determine an equilibrium site for a plant or organization manufacturing physical commodities, which minimizes total transportation costs of input and output distance. The initial site costs then can be re-evaluated via the introduction of another geographic factor variation, say labor. Labor cost savings at site two may compensate for additional transportation costs entailed by locating at the second site.

Isard (1956) is the foremost advocate of the use of the substitution principle for developing location theory. He asserts that it is only because of constant variations of prices and costs over space that location theory makes sense at all, and further, that such variations are constant only because transport cost is a function of distance. "The problem of production becomes a problem of choosing the right combination of the various types of capital, labor, land, and the transport inputs" (p. 28). Most of Isard's location work is based on the concept of the transport input as a representation of any economy's spatial relations, where such an input is understood simply as the movement of a unit of weight over a distance.

Now, although the substitution principle compactly shows how spatial tradeoffs enter economic theory, real problems develop when we attempt to apply such an analysis to empirical observations. First, location criteria must not be merely a tradeoff of one factor against another, but involves the mutual interdependence of all factors simultaneously. For another, even when transportation costs are included in a profit function, such costs, per se, in most production location decisions, have come to be recognized empirically as a comparatively

unimportant factor. Karaska and Bramhall (1969, p. 7) emphasize this point: "In only a few industries--heavy manufacturing and bulk processing like iron and steel and petroleum refining--is the transport likely to be a determining factor." However, they continue, "This is not to conclude that the transport. . . is negligible or unimportant, but rather that it needs to be re-examined and redefined in terms of the observed communication patterns and face-to-face contacts (our emphasis)."

In the present study, these factors are explicity incorporated. This situation is consonant with the general trend in the U.S. economy as discussed by Arrow (1974), Machlup (1962), Wills (1974) and others. In 1959, Machlup estimated that approximately 29% of the U.S. economy was devoted to the production, distribution, and reproduction of information. Recently, Porat (1975) has undertaken a reaggregation of the "information sector" (He includes all machines, workers and services devoted to the production, reproduction, and distribution of information) and found that approximately 50 percent of the U.S. economy was now devoted to this information sector rather than to the production of material goods. Porat's sector breakdown of the U.S. economy is shown in Figure 1.

Insert Figure 1 about here

The most prevalent form of analysis being used currently in location theory is that of linear programming. Such techniques and models have been extensively applied to problems in location theory since the late fifties. Works by Isard (1958), Lefeber (1958), Samuelson (1952), and others, used linear programming techniques to model processes of trade, price relationships in multi-location economics, and distribution patterns for particular commodities.

Of more immediate interest is the linear programming and heuristic models of the Swedish geographic location theorists (see especially Tornqvist, 1968, 1970, 1971). In the mid-sixties, Tornqvist attempted to solve the general location-allocation problem, that is, how to situate a number of facilities to serve an unevenly distributed population. Tornqvist devised an algorithm which allowed the facilities to search over the population surface to find locations which minimize cost or time to get to the facilities. Since location and facility capacity can vary in this algorithm, lower accessibility costs of smaller numbers of large facilities could be compared with increasing costs of creating more facilities with smaller capacity by running the algorithm several times with different numbers of facilities.

Information was first collected from all organizations. This included locations of suppliers of any inputs to the organization, total quantities used in one year's production, exact destinations and total amounts of finished products, individual amounts of any raw materials and finished products, transportation means, current product traffic, and terminal transportation charges for loading and unloading goods and raw materials. Materials required for a year's production were assigned locations according to the position of the supplies, and finished products according to their buyers.

The actual algorithm to complete transportation costs consists of a simulation in which any product unit is moved through hypothetical locations which correspond to Sweden's surface. The actual transportation costs for each location (the sum of transporting raw materials to the factory and transporting finished products from factory to market) is calculated according to the equation

$$TC_i = \sum_{j=1}^{n} p_j d_{ij}$$

where TC_i is the total cost of transporting raw materials to location i, or total cost of transporting finished products from i, p_j is the weight of raw material or weight of finished product, and d_{ij} is the transportation cost per unit weight of material (Tornqvist, 1971, p. 19).

This algorithm was then applied not merely to material flow but to the pertinent information flows of organizations which required direct face-to-face contact among spatial distant employees. Tornqvist examined differing organizational units (main offices and administrative boards) of which the actual contact patterns were known. All such contacts for a given organization were assigned grid coordinates on a map of Sweden, and units being studied were then moved about to each of the coordinates in the calculations. At each place, the employees in the area being studied would carry out a series of "contact programs," that is, they would contact the contracting parties in the rest of the contact system. Time expenditure and costs to carry out these programs at different places were measured and compared in a manner similar to the material goods case discussed above. The computer algorithm, NORLOC, which determines the optimal positions for a number of facilities with respect to total transportation cost is discussed in detail in Tornqvist (1971).

In our work on the current problem, we have followed the lead of Tornqvist and done essentially what Karaska and Bramhall have suggested, that is, we have defined a transport input for information in terms of the observed or reported communication patterns and face-to-face contacts. We have then examined a transport cost function simultaneously for material and information inputs. Finally, we have repeated the process using potential sources of information.

III. METHOD

A. Overview

By way of overview, the techniques used to conduct this study consist of identifying possible alternative research locations within the continental United States, examining the costs of performing the research functions of a federal Agency at each location, and using linear optimization to select that location which minimizes such costs. Locations are determined by imposing a fifty-by fifty mile grid on a map of the U.S. Electrical power costs for each location are calculated as are the costs associated with transporting a representative sample of material inputs from their present sources to each of one thousand three hundred twenty-five potential locations.

The cost of the acquisition of information is operationalized as the cost of travel to and from universities, industries, government installations and conferences. Environmental requirements (e.g., weather and altitude), are also imposed to identify those sites which meet the Agency's minimal research requirements.

A selection is then made as to the optimal locations for performing the specified research activities. Finally, major already established alternative locations are compared to determine the relative cost of conducting the Agency's research functions at these currently established locations.

B. The Map and Distance Calculations

A 50 X 50 mile grid coordinate system was constructed and superimposed on a map of the continental United States. Each cell was defined by its lower southeast corner, numbered positively in the x and y directions starting from the upper left hand cell. This procedure yielded a 36 X 58 matrix with a total of 1303 cells required to entirely cover the land mass (those cells without any

land surface, i.e., oceans and lakes, were omitted from further analysis). This map provided the basis for locating material and information sources.

...m one cell to another was calculated by the great-circle met... ...s method of calculation, ... possible to compensate for the fact that north-south boundaries of each cell ...re not perfectly parallel.

The latitude (lat.) and Longitude (long.), in radians, of the southeast corner of a cell in row X and column Y are given by the following formulas,

$$\text{Lat.} = .85521 - .0116355X, \text{ and}$$

$$\text{Long.} = 2.18166 - .0174533Y.$$

The angle between any two vectors from the origin of a spherical coordinate system from Cell 1 (Lat. 1, Long. 1) to Cell 2 (Lat. 2, Long. 2) on the surface of the sphere, is given by

$$\text{Angle} = \cos^{-1} [(\text{Lat. } 1)\cos(\text{Lat. } 2)\cos(\text{Long. } 2 - \text{Long. } 1) + \sin(\text{Lat. } 1)\sin(\text{Lat. } 2)]$$

This angle, when multiplied by the radius of the sphere (3960 miles in the case of the earth), yields the distance between the two points.

C. Power

The first criterion examined was availability and cost of electrical energy. The power cost at the Agency is considerable, amounting to a yearly average of approximately two and one-half million dollars. The total electrical energy consumed in FY1974 was 267,521,376 kWh with an average off-peak monthly half hour demand of 126,630 kW.

Power costs, incorporating both energy and demand changes for each 50 X 50 mile cell were acquired from the 1974 Typical Electric Bills booklet published by the Federal Power Commission. This publication provided power data for approximately 30% of the 1303 cell locations on the map. The power figure used in computing the cost for each cell was the lowest industrial rate available

for the cities listed based upon an energy consumption of 400,000kWh and a demand of 40,000kW. To compute the power costs for those cells in which a power rate was not directly obtainable, a process of extrapolation was used. This was done by av[illegible] as many cells in which power was directly obtainable from the Typical [illegible] Bills booklet and placing that figure into those cells that were directly adjacent to the cells from which the average was obtained. This allowed the power rate for each unknown cell to become a direct function of those rates that were known. The power data for each 50 X 50 mile cell were claculated by this method with extrapolation taking place only within each state and not across state boundaries.

D. Material Input

Another major cost factor in the location problem is the transportation of material inputs. A total of 300 material inputs to the research complex were systematically selected from the agency's receiving station. The sample was obtained by selecting the five heaviest shipments that arrived each day over a four-month period (January-April 1975). The five heaviest shipments, rather than a random sample of five shipments per day, were selected in order to maximize the cost of transportation relative to the cost of power. These 300 items represented 68% of the total input weight to the Agency. Each item was assigned a set of grid coordinates which identified its source of origin (i.e., the place from which it was shipped). Weight of each item and mode of transportation (i.e., rail, truck, air) were also recorded. Eighty-five percent (85%) of the material was delivered by truck, 14% was shipped by air, and 1% was transported by rail.

Truck transportation rates per pound per mile were obtained by averaging the estimated costs given by three trucking companies which shipped materials throughout the United States similar in weight to those samples in this study.

Plane transportation rates per pound per mile for general commodities were obtained through the Civil Aeronautics Board Tariff Book #169. Rail rates were obtained through Southern Pacific Railways. Since Southern Pacific was the sole shipper in the materials selected for the sample, no other shippers were ulted.

ince the cost of transportation varies as a function of distance, it was necessary to provide incremental costs for the modes as indicated in Table 1. The shipping routes used by trains and trucks are not as direct as those of planes. To correct for this, shipping distances of less than 500 miles were multiplied by a factor of 1.3. Distances greater than 500 miles were multiplied by a factor of 1.35 (See Tornqvist, 1971).

Insert Table 1 about here

These data were analyzed in the linear program to compute the cost of transporting the 300 material inputs from their original cell locations to each of the 1303 cells. Since the sample consisted of 68% of the total shipping weight, this cost value was multiplied by a factor of 1.47 to create an estimate of the total cost of shipping incurred by the Agency.

E. Environmental Criteria

After cell locations were examined for comparative power, material transport costs, and information input costs (to be discussed shortly), weather and altitude criteria were applied to each cell. These criteria included temperature, wind velocity and number of clear days. A review of available information revealed that all locations met the weather requirements specified by the Agency. Altitude remained an important environmental criterion. Cell locations with mean altitudes greater than 3,000 feet were eliminated as possible location sites.

F. Current Sources of Information (Analysis I)

As indicated earlier, the cost of acquiring information is being operationalized as the travel to and from sources from which information can be gathered that will be useful for ongoing and further research and development within the Agency. A review of the Agency's university travel records indicated that a total of 321 trips were made to universities during FY1975 by Agency personnel. For comparison with the potential sources of information in Analysis II, it was necessary to restrict the sample to those travel vouchers which included contract and/or grant numbers, in order to identify the area of contract specialization under which the trip was made (See Section G).

The location of each university visited and the number of trips to that university were recorde[illegible] ielding a total of 66 trips. These 66 trips are 20% [illegible] the total travel to [illegible]iversities. Multiplying the cost of travel calculated [illegible] these 66 trips by [illegible]tor of 5 provides an est[illegible]ate of the total cost of tra[illegible] to universities [illegible]ncy personnel.

The pay and travel [illegible]nch of the Agency retains all records of travel to other locations by Agency personnel. A random sample 10%) was drawn from the travel records of FY1975. These travel dat[illegible] were coded into three categories. The first category was travel to industry for the purpose of setting up contracts or reviewing contracts a ready in progress. 180 trips were recorded with reference to travel to industry.

The second category was travel to government installations (e.g., NASA installations; Army, Navy, and Air Force bases). Within this category there were 212 trips. The third category was travel to conferences and/or conventions. In all, 62 trips to conferences and/or conventions were identified.

The destination for each trip was recorded. When multiple stops were included within one trip, the location that was farthest in distance from the

agency was selected. The appropriate grid location for each destination and the number of trips made to that cell location were then coded. Since the sample was 10% of the total travel, the cost of travel to industries, government installations, and conferences and/or conventions were multiplied by a factor of 10 to provide an estimate of the total cost of travel to these facilities.

Potential Sources of Information (Analysis II)

In order to undertake the examination of potential rather than actual sources of information, it was necessary to ascertain where the information most likely to be useful to the Agency could be obtained. Analysis of the Agency's research and development functions and discussions with Agency personnel suggested three primary sources: universities, industry, and conferences/conventions.

1. Universities. During the month of November, 1975, a complete review of the agency's travel records for Fiscal Year 1975 was conducted. The travel records of each branch were used to identify all travel by Agency personnel to universities and colleges for the purpose of monitoring contracts and/or grants. The Agency codes each contract and/or grant with a university by the area of contract specialization. For each trip identified, the area of contract specialization was recorded. As indicated in the previous section this process yielded 66 trips for the purpose of monitoring specific contracts and/or grants. These contracts and/or grants fell into 11 separate areas of contract specialization.

Using A Rating of Graduate Programs (Roose and Anderson, 1970), the top ten universities in each area of departmental specialization were identified. The departmental specializations identified by Roose and Anderson (1970) were not identical with the areas of contract specialization used by the Agency. In some cases, several areas of departmental specialization were subsumed within one area of contract specialization. In other instances, several areas of contract

specialization were subsumed within one area of departmental specialization. Through this process, the eleven original areas of contract specialization were transformed into 8 areas of departmental specialization. For each area of departmental specialization, the following information was coded: the number of trips made by Agency personnel to monitor contracts and/or grants in this area of specialization during FY1975 and the cell coordinates of the top 10 universities within that specialization.

As indicated earlier, the cost of travel to these universities was multiplied by a factor of 5 to yield an estimate of the total cost of travel to universities.

2. Industry. The 1974/75 Aerospace Facts and Figures provided a listing of the major industrial contractors with federal agencies as of 1973. This listing is based upon the net value of prime contracts awarded during FY1973. For each industry, the major facilities used in research and development for government agencies were identified. The cell coordinates for each facility were coded.

The 180 trips made to industries by Agency personnel were distributed equally across all potential industries. Since the 180 trips were based on a 10% sample, the cost of travel to the potential industries was multiplied by a factor of 10 to create an estimate of the total cost of travel to the potential industries.

3. Conferences and/or Conventions. Rather than proposing a list of potential government installations or conference and/or convention sites, the data collected on the actual information sources for these two categories were used. This, in effect, holds these two categories of travel constant, thereby permitting a comparison between the current travel costs to universities and industries with the cost of travel to potential university and industrial sites.

H. Computational Algorithm. The cost algorithm essentially consists of simulation in which each of the material inputs and information sources are first "transported" to the first grid location and a cost value is calculated for that cell. This cost is added to the power cost for that cell, following which the material and information input [illegible] location and associated costs are added to that cell's power cost, and so forth. The following formula summarizes the computational algorithm:

$$Z_j = k_j + \sum_{n}\sum_{m} [r_m(d_{jn}) \quad (\Sigma w_{im})] + 2 \sum_{n} [(d_{jn}a_{jn})(u_n + i_n + g_n + c_n)]$$

where:

Z_j is the total cost for cell j (j = 1, 2, . . . , 1303),

k_j is the lowest power cost in the jth cell for the amount of power consumed at the Agency,

r_m is the average transportation rate which is mode-specific, i.e., has differing series of values for m = 1, 2, 3 depending on whether the input is shipped by rail, truck, or plane, and further values depending on what distance range or the specific rate schedule under which input distance falls,

w_{im} is the weight of the ith input travelling by mode m,

d_{jn} is the distance from the jth input cell to the nth input cell, according to the great-circle method formula:

$$d_{jn} = \text{Angle } (3960 \text{ miles})$$

$$\text{Angle} = \cos^{-1} [\cos(\text{Lat. } 1)\cos(\text{Lat. } 2)\cos(\text{Long. } 2 - \text{Long. } 1) + \text{Long. } 1) + \sin(\text{Lat. } 1)\sin(\text{Lat. } 2)]$$

where:

Lat. 1 = Latitude of Cell 1,

Lat. 2 = Latitude of Cell 2,

Long. 1 = Longitude of Cell 1,

Long. 2 = Longitude of Cell 2;

a_{jn} is the one-way rate of personal air travel over distance d_{jn},

u_n is the number of trips to universities within the nth cell.

i_n is the number of [illegible] industries [illegible]

g_n is the number of trips to government facilities within the nth cell,

c_n is the number of trips to conferences and/or conventions within the nth cell;

subject to these constraints:

$k_j \geq$ 18,417,351 KWh/month, i.e., the existing value of the Agency, and all variables in the cost function ≥ 0.

In other words, the expression Z_j provides the comparative cost of supplying the jth location (i.e., cell) with an amount of power greater than or equal to the amount currently utilized by the Agency per month and accounts for a large representative sample of material and information input to that square. Cells which satisfied the altitude and weather criteria were then rank ordered.[1]

IV. RESULTS

Throughout this study, two separate approaches to the problem of facilities location have been emphasized. Analysis I solves the location problem with respect to the current sources of material and informational input. Analysis II focuses on the use of potential information sources as the locational criteria, i.e., those universities with the most highly rated graduate schools and those industries that receive the greatest prime contracts from the Agency. The results are presented separately for the two types of analyses.

A. Analysis I: Current Sources of Information

A total of thirteen hundred three (1303) cell locations were tested for combined electrical power, material, and information costs. The obtained figures

for these expenses ranged a high month for cell 13,52 in ... New York, to a low of $..., month for cell 5,3 which is in southwestern Washington. The cost at the Agency was $3?0,602.

By imposing the combined input cost for the Agency as the minimal reference criterion, eleven hundred eighty-eight (1188) cells were identified as being in excess of the minimal amount; these cells were discarded from further analysis. The remaining one hundred fifteen (115) cells all had total costs less than that of the Agency.

These one hundred fifteen cells were then examined on the altitude criterion of a maximum of 3,000 feet elevation. This procedure eliminated an additional fifty-eight cells, most of which were located in the Rocky Mountain states.

Of the remaining fifty-seven cells, fifty-five of them clustered in the Pacific Northwest region of Washington and Oregon. Of the other two cell locations which had lower total cost than the Agency and meet the altitude criterion, one was in the Sacramento Valley region of Central California, and one was located on the state border between Oklahoma and Texas.

A computer-generated map which displays these findings is provided in Figure 2. The cell which contains the Agency is indicated by an "N" at coordinates 18,3 on the map. The 1188 cells which exceeded the cost at the Agency are indicated by the symbols 4 through 9, plus an asterisk. Each successive symbol from 4 to 9 represents a 10% increase in total cost. Thus, the symbol "4" represents 100-110% of the cost of the Agency. The symbol "8" represents a cost of 140-150% over that of the Agency. "9" indicates a cost of 150-170%, and "*" represents a cost greater than 170%. Those cells which had lower combined cost than the Agency but did not meet the altitude criterion (i.e. they were located at greater than 3000 feet elevation) are marked with an "A". Those cells with total combined cost less than that of the Agency

which did meet the altitude criterion are identified by the symbols $, 0, 1, 2, and 3. $ indicates a cost of less than 80% of the Agency's cost. "0" through "3" represent 5% increments from 80% to 100%. The least cost cell is indicated by an "L;" the highest cell is indicated with an "H."

Insert Figure 2 about here

The analysis just described examined all of the potential locations within the continental United States. The alternative of moving the current Agency research and development functions to one of these new locations is highly unlikely because of the very high capital investment in present facilities. What is more realistic is that an already existing government location would be assigned the Agency's current functions so as to utilize already existing facilities. To examine this possibility, all of the present related federal installations were compared. The results of this analysis are provided in Table 2. All sixteen facilities are listed by their respective cell coordinates. The locations are rank ordered by increasing total cost. For each location, the total cost is given as well as the individual costs for power, shipping, and travel. The altitude, rounded to the nearest 50 feet, is also provided.

Insert Table 2 about here

As can be seen from this table, the Agency was ranked number 1 and had the least cost ($300,602/month) associated with performing its functions. Were these functions to be moved to any other present federal location, it would cost more to perform them than at the present Agency location. The lowest (16th) ranked location (cell 15,49) had a total cost close to twice

that of the Agency ($580,482/month). The middle ranked (ninth) location, had a total cost of $433,536/month and would require a monthly expenditure approximately half again as great as the current cost of the Agency.

B. Analysis II: Potential Sources of Information

Analysis II examined the potential rather than the actual information inputs. Again, thirteen hundred three cell locations were tested for combined power, material input, and potential information input costs. The obtained figures ranged from a high of $957,048/month for cell 13,52 in Long Island, New York, to a low of $235,670 for cell 5,3 in southwestern Washington. The total combined cost for the Agency, utilizing its potential information sources, was $285,612.

Comparing each of thirteen hundred two cells with the criterion cost of the Agency, twelve hundred six (1206) were found which exceeded this value; they are indicated on the map by cost increment but were deleted from further analysis. The remaining ninety-seven (97) cells had total costs less than the Agency.

As was done in Analysis I, these ninety-seven cells were examined as to whether they exceeded the maximum altitude of 3,000 feet. After this examination, forty (40) more cells were eliminated from further analysis. This left fifty-seven (57) cells which met the altitude criteria and had less total cost than did the Agency.

With the exception of one cell located in the Sacramento Valley region of California, all remaining cells which met the criteria were located in the Pacific Northwest region of Washington and Oregon. Figure 3 presents a computer-generated map which summarized these data.

Insert Figure 3 about here

As was done in Analysis I, the alternative federal locations were ranked in terms of increasing total cost. Table 4 shows that the present Agency location was again ranked first as the least cost location ($285,612/month). Cell 15,49 was again ranked last as the most expensive location ($539,986/month). Cell 18,49 moved from ninth to fifth rank with a total monthly cost of $393,615. The new middle ranked (ninth) location (Cell 23,07, previously ranked sixth) had a cost of $403,289/month.

Insert Table 3 about here

By comparing Tables 2 and 3 it can be seen that every location had a lower cost in the potential information analysis than it had in the actual information analysis. The cost differential between the two analyses differed considerably depending upon specific location. For example, Cell 18,49 saved $40,000/month, because Cell 26,19 was already more optimally located than Cell 18,49 (with the exception of altitude).

C. Validation of the Location Model

The computer algorithm created to undertake the present model is a form of simulation modeling. As such, the results are only as good as the data which are provided as input to the program. Yet it should be pointed out that unlike many simulations, the present model uses a comparative, rather than an absolute, technique; that is, the same data are applied to all locations in order to draw comparative rather than absolute conclusions. Even if the data do not perfectly reflect the actual costs at the present Agency location, they do reflect

comparative differences between the Agency and all other locations. Hence, inaccuracies in the data do not introduce serious bias in favor of any one location.

It is, nevertheless, useful to know how accurate the data utilized in the present analysis are. To undertake this assessment, the computer results were compared with budgetary data from FY1975. What follows describes that comparison.

The power cost for the Agency generated by the computer simulation was $189,883/month. The total power cost per month at the Agency was $218,888, a difference of $29,005. The explanation for the discrepancy lies in the fact that the power figures used in the simulation were based upon electric costs only and did not include natural gas costs. Records of monthly gas costs provided by Agency personnel range from $25,000 to $30,000 per month. When this amount for gas power is added to the electrical power costs, the computer estimate appears quite accurate.

The only budgetary data available indicated that the Agency allocated $3,083/month for shipping expense. The shipping costs calculated in the computer analysis amounted to $29,038/month. The difference of $25,955/month is considerable. It must be noted, however, that the figure of $3,083/month does not include items that are shipped FOB nor does is include the cost of shipping items purchased under contracts and/or grants. Because it is based on a large sample of the items actually shipped to and received at the Agency, the figure of $29,038 generated by the computer is believed to be an accurate estimate of the total cost for shipping all items to the Agency.

The Agency budgeted $82,583/month for the purpose of travel. The calculations obtained from Analysis I estimated a cost of $81,681/month, a difference of $902/month. This estimate is well within acceptable limits.

Since the costs calculated for the Agency by the computer algorithm approximate the actual budget expenditures at the research center, the methods used in this study are assumed to have provided adequate information for comparison among all potential locations.

V. DISCUSSION

In this study the attempt has been made to extend one of the traditional specializations of economics, location theory, by explicitly including the cost of acquiring information in the functional equations. The results obtained demonstrate the importance and utility of including information as a part of the optimizing function. From a theoretical point of view, however, there are several qualifications which seem appropriate.

First, traditional location theory attempts to minimize the costs of simultaneously obtaining raw materials and distributing finished products. While the function in the present model included travel costs both to and from the Agency (as in traditional location theory), those costs were primarily for the purpose of acquiring information and only minimally for the costs of disseminating the information (specifically, the travel to conventions for presenting papers). In this sense the model utilized in the present research departs somewhat from its traditional form; future efforts should probably attempt to include the full range of dissemination costs as well as acquisition costs.

Second, the study was based upon the assumption that direct face-to-face communication between the Agency's research staff and its external sources of information was essential in order for the Agency to fulfill its tasks. Certainly, other forms of communication, such as letter and telephone, are also important, though they were not included in the present research. Furthermore, in an era in which teleconferencing and other significant technological

alternatives to travel costs are being explored, placing primary emphasis on direct, face-to-face communication may be bordering on anacronistic.

Third, the cost figure assigned to communication was highly restricted. Several additional factors which most likely contribute to the cost of communicating were omitted. For example, neither the cost of the time spent in communicating (as in the form of salaries) nor the cost of support personnel and/or materials (as in having a secretary arrange travel plans or preparing materials) were included.

Fourth, any significant theory of the economics of information must come to grips with the problem of measuring information. As yet, no standard unit exists for quantifying information. Uncertainty (entropy) measures, which comprise the only significant attempt to solve this problem, have so far proved largely intractable to practical applications. Since the amount of information obtained by personnel in the present study was unknown, the problem was circumvented by substituting the cost of acquiring information for the actual cost of the information.

Finally, from the viewpoint of economic theory, once a unit measure has been established it will be important to assign a "value" to the unit. The face-to-face communication contacts which were examined in the present analysis probably ranged from worthless to highly valuable, though no attempt was made to assign value to any of them. Only when we know how to assign value directly to a unit of information will it be possible to formulate a significant economic theo[illegible]rmation.

[illegible]ese limitations, the results indicated that from the standpoint of power c[illegible], mat[illegible]rial shipping costs, e[illegible]ronmental criteria and the costs of acquiring information, the present location of the Agency was nearly optimal. Not only was it ranked in the top four percent (4%) of the possible nationwide

locations in both the actual and potential information analyses, but it also had the lowest total cost value of all present alternative federal installations.

It should be mentioned that the techniques used in the location simulation did not bias the results in favor of the Agency's present location. While it is true that the current functions of the Agency were utilized for the parameters of the system, it was entirely possible that those functions could have been more cost-effectively met at many other locations. In fact, such was the case, since approximately 4% of the cells were identified as being less expensive than the present Agency location. None of these cells, however, contained other federal facilities, and hence, did not constitute very viable alternatives.

A healthy word of caution does seem in order, however. As with any simulation, the findings should be interpreted with care. Every simulation is an abstraction which selects certain aspects of a process and omits others. The elements selected for inclusion in the present analysis were considered most important in terms of cost. Yet other apsects might also be included. For example, the cost of labor differs considerably by geographic region. While the majority of the Agency's personnel are classified as "government service" and hence would be paid the same amount wherever they were located, there still remains a sizeable number of employees who do not have G.S. ratings and would therefore receive wages in accordance with the local labor market. Yet low wages tend to be associated with those geographic areas that possess few skilled workers. When this is combined with the fact that the Agency requires a fairly skilled staff of support workers, it becomes apparent that locating the Agency in a region where the labor force is unskilled though cheap is

...er variables, such as economic impact on surrounding community, air pollution, effect on natural resources, etc., could, of course, be mentioned.

But enough has been said to illu... ...the point that the attempt has been made in the present simulation ... those variables which were considered to be the most important from a cost-effectiveness standpoint. Inclusion of other variables must await further extensions of the present model.

Finally, and beyond the narrow confines of the present re... economists such as Arrow (1974) have indicated that the inclusion of info... economic theory is an important contribution. Likewise, communication sch... (e.g., Mills, 1974) have indicated that the joining of information and co...tion concepts to the more advanced theoretic formulations of economics ... important implications for the development of communication theory. It appears that the areas of overlap between the two disciplines provide an important area for future research, one which, if explored from their respective perspectives, will be beneficial to both the field of communication and the field of economics.

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FA TS

For information ab puter algorithm and program contact:

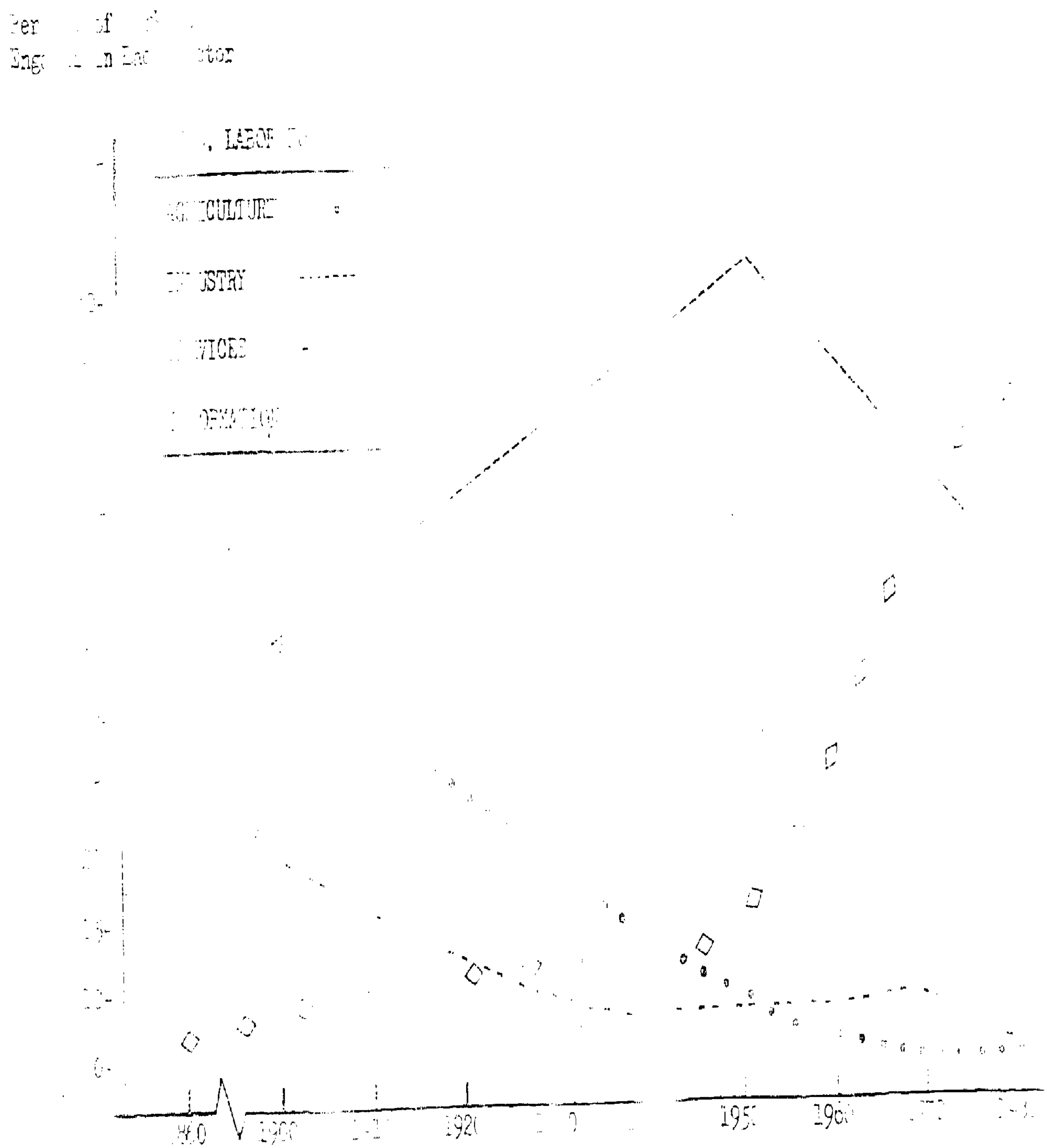


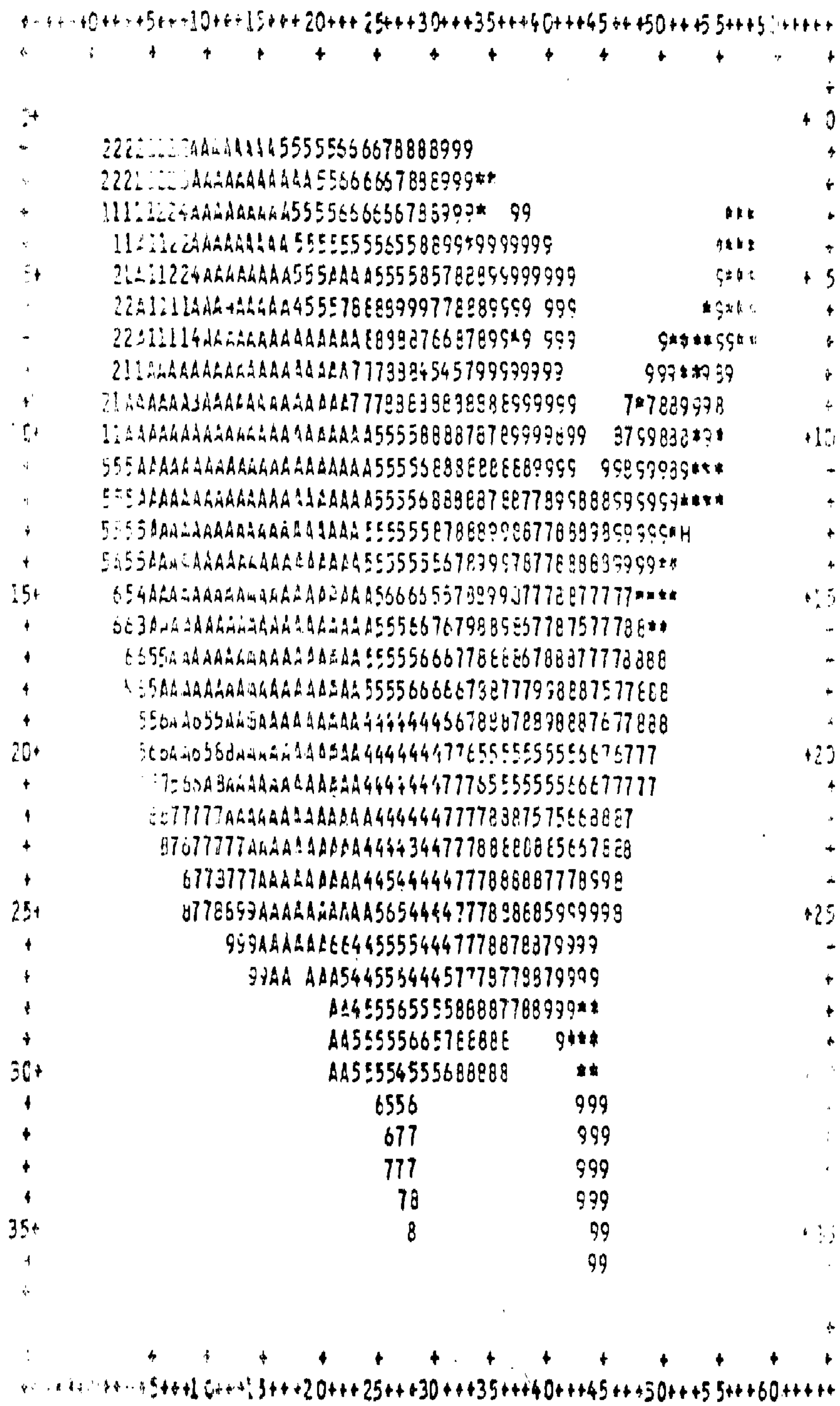
Figure 1. U.S. Labor Force from 18 to present: ...ctor Aggregation Showing ... Increase in Percent of Workers Engaged ... Information Production ...
Porat, 1975).

Figure 2

COST MAP FOR ANALYSIS I

(USING PRESENT INFORMATION SOURCES)

Y INDEX



COST INDEX

SYM	PERCENTAGE OF PRESENT COST
	- 80
	80 - 85
	85 - 90
	90 - 95
	95 - 100
	100 - 110
	110 - 120
	120 - 130
	130 - 140
	140 - 150
	150 - 170
	170 % -

ALTITUDE > 3000 FEET

H MOST EXPENSIVE LOCATION NOT EXCLUDED BY ALTITUDE (13,32) COST = $ 1,002,455.00

L LEAST EXPENSIVE LOCATION NOT EXCLUDED BY ALTITUDE (5, 3) COST = $ 254,148.31

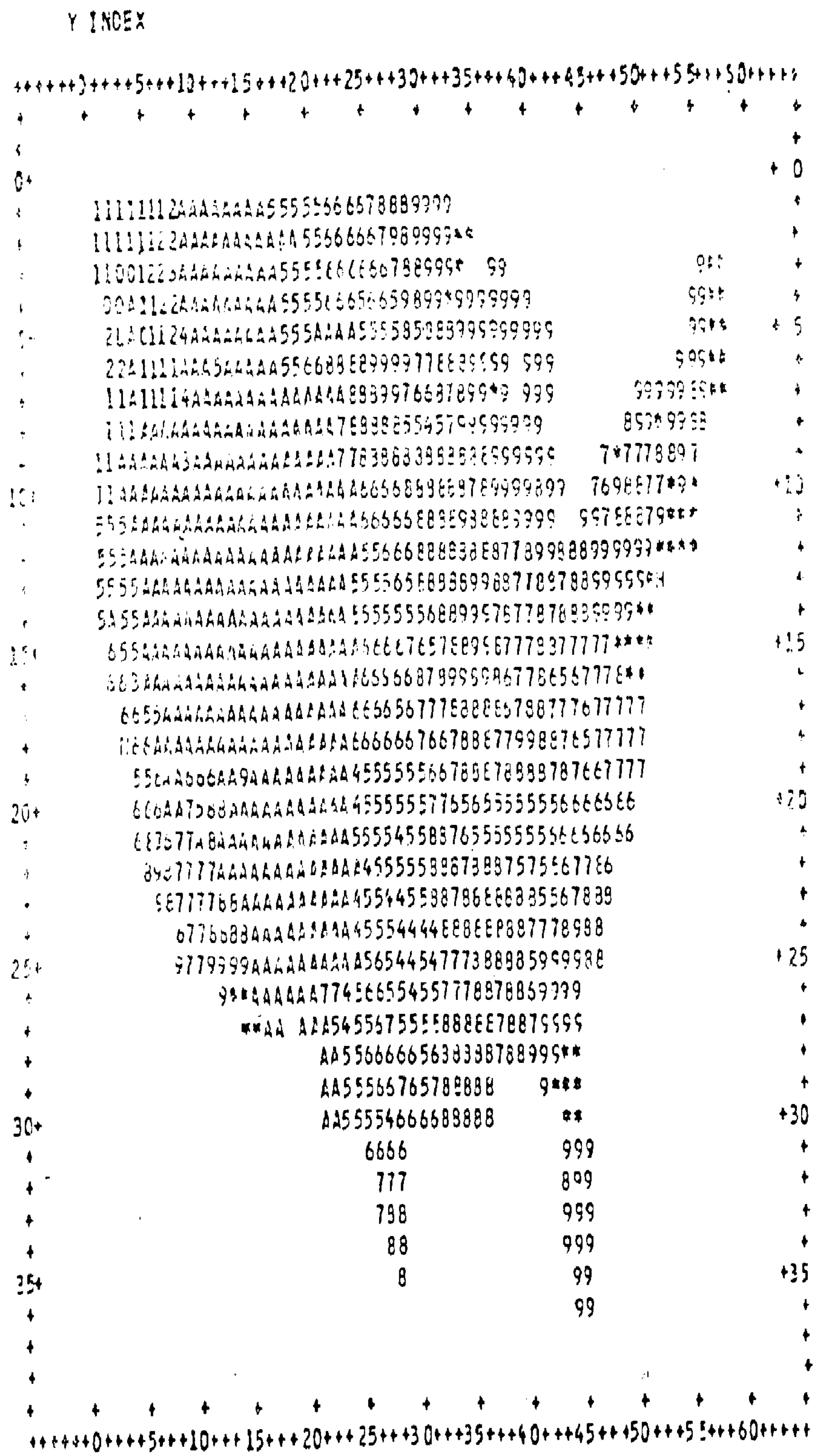
N PRESENT AGENCY LOCATION (18,) COST = $ 300,602..1

Location

Figure 3

***** COST MAP FOR ANALYSIS II *****

(USING CLOSEST UNIVERSITY AND INDUSTRY CONTACTS)



COST CODES:

SYMBOL	PERCENTAGE OF PRESENT COST
$	— [illegible] %
0	[illegible] — [illegible] %
1	[illegible] — [illegible] %
2	[illegible] — [illegible] %
3	95 — 10[illegible] %
4	10[illegible] — [illegible] %
5	[illegible] — [illegible] %
6	12[illegible] — 1[illegible]0 %
7	1[illegible]0 — 140 %
8	140 — 150 %
9	150 — 170 %
*	170 % —

A ALTITUDE > 3000 FEET

H MOST EXPENSIVE LOCATION NOT EXCLUDED BY ALTITUDE: (13,57) COST = $ 957,047.54

L LEAST EXPENSIVE LOCATION NOT EXCLUDED BY ALTITUDE: (5, 3) COST = $ 235,670.44

N PRESENT AGENCY LOCATION: (18, 3) COST = $ 285,611.51

Location

TABLE 1

Cost Per Pound Per Mile
for Three Modes of Transportation

		MILES		
		0-1000	1001-2000	2001-3000
	TRUCK	$.0001137/lb./mi.	$.00007588/lb./mi.	$.00006277/lb./mi.
MODE	PLANE	$.000312/lb./mi	$.000148/lb./mi.	$.0000983/lb./mi.
	RAIL	$.0000958/lb./mi.	$.0000819/lb./mi.	$.0000756/lb./mi.

TABLE 2

ANALYSIS I: RANK ORDER OF SELECTED FEDERAL R & D INSTALLATIONS BY TOTAL COST

Rank	Cell Location	Symbol	Total Cost	Power Cost	Shipping Cost	Univ. Travel	Ind. Travel	Gov't. Travel	Conf/Conv Travel	Altitude
1.	(18,03)	N	$300,602	$189,883	$29,038	$4,532	$34,010	$37,752	$5,387	500 ft.
2.	(29,30)	5	$338,506	$223,218	$44,340	$4,160	$31,747	$25,861	$9,180	100 ft.
3.	(19,09)	A	$364,232	$263,874	$34,158	$3,664	$26,090	$32,054	$4,391	3,000 ft.
4.	(26,19)	A	$378,492	$276,214	$42,469	$3,417	$22,575	$27,911	$5,905	5,000 ft.
5.	(22,07)	7	$411,504	$309,688	$34,407	$4,005	$26,065	$33,176	$4,163	1,500 ft.
6.	(23,07)	7	$412,451	$310,056	$35,485	$4,046	$25,586	$33,196	$4,081	250 ft.
7.	(22,06)	8	$423,459	$316,042	$33,664	$4,330	$29,342	$35,437	$4,643	1,500 ft.
8.	(25,40)	9	$425,226	$282,890	$56,460	$4,664	$45,556	$24,120	$11,536	1,000 ft.
9.	(18,49)	8	$433,336	$256,185	$68,036	$5,560	$62,591	$26,946	$14,019	100 ft.
10.	(18,49)	8	$433,336	$256,185	$68,036	$5,560	$62,591	$26,946	$14,019	100 ft.
11.	(12,33)	8	$433,742	$311,852	$48,243	$3,440	$36,803	$24,022	$9,382	1,000 ft.
12.	(29,35)	8	$436,582	$305,866	$50,252	$4,718	$39,552	$25,514	$10,626	100 ft.
13.	(29,36)	8	$440,310	$305,820	$51,882	$4,813	$41,230	$25,617	$10,948	100 ft.
14.	(12,43)	8	$448,354	$295,322	$58,869	$4,549	$52,573	$25,037	$12,004	1,000 ft.
15.	(31,45)	9	$497,239	$319,485	$67,668	$6,109	$59,806	$30,216	$13,946	100 ft.
16.	(15,49)	*	$580,482	$404,583	$67,367	$5,407	$62,473	$26,780	$13,873	100 ft.

Location

TABLE 3

ANALYSIS II: RANK ORDER OF SELECTED FEDERAL R & D INSTALLATIONS BY TOTAL COST

Rank	Cell Location	Symbol	Total Cost	Power Cost	Shipping Cost	Univ. Travel	Ind. Travel	Gov't. Travel	Conf/Conv Travel	Altitude
1.	(18,03)	N	$285,612	$189,883	$29,038	$ 2[illegible]	$23,522	$37,752	$ 5,387	5[illegible] ft.
2.	(29,30)	5	$331,467	$223,218	$44,340	$2,862	$26,006	$25,861	$ 9,180	100 ft.
3.	(19,09)	A	$355,808	$263,874	$34,158	$ 762	$20,568	$32,054	$ 4,391	3,000 ft.
4.	(26,19)	A	$377,229	$276,214	$42,469	$2,268	$22,461	$27,911	$ 5,905	5,000 ft.
5.	(18,49)	7	$393,615	$256,185	$68,036	$1,243	$27,186	$26,946	$14,019	10[illegible] ft.
6.	(18,49)	7	$393,615	$256,185	$68,036	$1,253	$27,186	$26,946	$14,019	1[illegible]
7.	(23,40)	8	$401,527	$282,890	$56,460	$1,539	$24,982	$24,120	$11,536	1,0[illegible] ft.
8.	(22,07)	8	$402,169	$309,688	$34,407	$ 185	$20,550	$33,176	$ 4,163	1,5[illegible] ft.
9.	(23,07)	8	$403,289	$310,056	$35,485	$ 40	$20,430	$33,196	$ 4,081	250 ft.
10.	(22,05)	8	$412,133	$316,042	$33,664	$ 438	$21,909	$35,437	$ 4,643	1,500 ft.
11.	(12,43)	8	$416,413	$295,322	$58,869	$ 486	$24,695	$25,037	$12,004	1,000 ft.
12.	(12,33)	8	$417,945	$311,852	$48,243	$ 761	$23,685	$24,022	$ 9,382	1,000 ft.
13.	(29,35)	8	$426,634	$305,866	$50,252	$2,542	$26,833	$25,514	$10,626	100 ft.
14.	(29,36)	8	$423,751	$305,820	$51,882	$2,504	$26,980	$25,617	$10,948	100 ft.
15.	(31,45)	9	$464,900	$319,485	$67,668	$2,889	$30,687	$30,216	$13,946	100 ft.
16.	(15,49)	*	$539,986	$404,583	$67,367	$ 862	$26,521	$26,780	$13,873	100 ft.